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Metal Concentrations in Surface Soils of Thompson, Manitoba, September 2001

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EXECUTIVE SUMMARY

In response to reports of high concentrations of nickel (Ni) in soil at Port Colborne, Ontario, Canada, a joint Manitoba Conservation and INCO study was conducted in September 2001 to determine the levels of Ni and other elements in surface soils in the city of Thompson, Manitoba.

Soil samples were collected from 62 locations in the city of Thompson in September 2001. Samples were extracted from the top 2 cm of the soil profile and analyzed for soil pH and the concentration of metals and metalloids. Sample sites included schoolyards, parks and playgrounds, and residential properties. The laboratory analysis results were evaluated by comparing them to established Canadian soil quality guidelines and interim remediation criteria.

The Canadian soil quality guideline for Ni is 50 µg/g (all land uses) and is intended for protection of the environment. A guideline for Ni to protect human health has not been established. This guideline was exceeded at 45 of the 62 sites sampled. Sites that exceeded the guideline were distributed throughout the city, but the highest values tended to be at sites closer to the smelter. The highest mean concentration of Ni at the Thompson sites was 299 µg/g, which was many times lower than the levels of Ni reported in soil at Port Colborne. A health risk assessment for Port Colborne concluded that there was a very low risk to human health (including young children) if the concentration of Ni in the soil was lower than 8,000 µg/g. Based on this, the risk of human health effects from exposure to the Ni in the surface soils in Thompson is considered to be extremely low.

Mean concentrations of chromium (Cr), copper (Cu) and lead (Pb) were generally low at the sites sampled, but did exceed soil quality guidelines at a small number of sites. Mean concentrations of cadmium (Cd) exceeded the agricultural use guideline at 14 of the sites. However, the human health guideline for Cd in soil intended for residential/parkland use was not exceeded. Based on these results, the risk of human health effects from the Cr, Cu, Pb, and Cd found in Thompson soils is also considered to be extremely low.

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SOMMAIRE

À la suite de rapports faisant état de fortes concentrations de nickel (Ni) dans le sol à Port Colborne, en Ontario (Canada), Conservation Manitoba et INCO ont effectué une étude conjointe en septembre 2001 pour déterminer les niveaux de Ni et d'autres éléments dans des sols de surface de la ville de Thompson, au Manitoba.

Des échantillons de sol ont été prélevés dans 62 endroits de la ville de Thompson en septembre 2001. Il s'agissait d'échantillons tirés des deux premiers centimètres de la couche supérieure du profil de sol. On les a analysés pour déterminer le pH du sol et les concentrations de métaux et de métalloïdes. Ces échantillons provenaient notamment de cours de récréation, de parcs, de terrains de jeu et de propriétés résidentielles. On a évalué les résultats des analyses de laboratoire en les comparant aux recommandations canadiennes pour la qualité des sols déjà établies et aux critères provisoires d'assainissement.

La recommandation canadienne pour la qualité des sols en ce qui concerne le nickel est de 50 µg/g (quelle que soit l'utilisation du sol) et a pour but de protéger l'environnement. Une recommandation visant la protection de la santé humaine contre le Ni reste à établir. Dans 45 des 62 sites testés, le niveau de nickel dépassait les 50 µg/g. Ces sites étaient dispersés dans toute la ville, mais on avait tendance à trouver les niveaux les plus élevés dans les endroits situés près de la fonderie. La plus forte concentration moyenne de nickel dans les sites testés à Thompson s'élevait à 299 µg/g, ce qui est largement inférieur aux niveaux de nickel constatés dans le sol de Port Colborne. Selon une appréciation des risques pour la santé effectuée à Port Colborne, le risque pour la santé humaine (y compris celle des jeunes enfants) est extrêmement faible si la concentration de nickel dans le sol est inférieure à 8 000 µg/g. Par conséquent, les risques pour la santé humaine d'une exposition au nickel contenu dans les sols de Thompson semblent être extrêmement faibles.

Les concentrations moyennes de chrome (Cr), de cuivre (Cu) et de plomb (Pb) étaient généralement peu élevées dans les sites testés, mais, dans un petit nombre d'entre eux, elles dépassaient les niveaux fixés dans les recommandations pour la qualité des sols. Dans 14 des sites testés, les concentrations moyennes de cadmium (Cd) dépassaient les niveaux établis dans la recommandation pour l'agriculture, mais pas ceux établis dans la recommandation pour la santé humaine en ce qui concerne les sols destinés à devenir des zones résidentielles ou des parcs. Ces résultats permettent de conclure que le chrome, le cuivre, le plomb et le cadmium trouvés dans les sols de Thompson semblent également présenter des risques très minimes pour la santé humaine.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY I

SOMMAIRE II

ACKNOWLEDGEMENTS III

TABLE OF CONTENTS IV

LIST OF FIGURES V

LIST OF TABLES V

INTRODUCTION 1

SOIL SAMPLING METHODS AND LABORATORY ANALYSIS 1

RESULTS AND DISCUSSION 5

- Soil Quality Guidelines 5
- Concentrations of Nickel 6
- Concentrations of Other Metals 11

SUMMARY AND RECOMMENDATIONS 17

REFERENCES 18

APPENDIX 19

LIST OF FIGURES

Figure 1. Aerial photograph of Thompson, MB, showing the location of sample sites 3

Figure 2. Photographs of soil sampling..... 4

Figure 3. Aerial photograph of Thompson, MB, showing the ranges in nickel concentration in surface soil samples..... 10

Figure 4. Aerial photograph of Thompson, MB, showing the ranges in cadmium concentration in surface soil samples..... 12

LIST OF TABLES

Table 1. Sites sampled in Thompson, September 2001..... 2

Table 2. List of elements analyzed in surface soil samples collected in Thompson, September 2001..... 5

Table 3. Mean concentrations of nickel in surface soil samples collected from 62 sample sites in Thompson, September 2001..... 9

Table 4. Summary of metal concentrations (nickel excluded) in surface soil samples collected from 62 sampling sites in Thompson, September 2001.....11

INTRODUCTION

The contamination of soil with nickel (Ni) emitted from the International Nickel Company Ltd. (INCO) smelting facility in Port Colborne, Ontario, has raised concerns about the effect on residents' health. INCO also has a mining and smelting facility in the city of Thompson in northern Manitoba. The Government of Manitoba has conducted environmental monitoring of forest communities in the vicinity of Thompson since 1976. Findings from this monitoring program indicate that emissions from the INCO smelter have resulted in elevated concentrations of Ni, copper (Cu), iron (Fe), cobalt (Co), and arsenic (As) in soils in surrounding forests (Wotton and Hogan 1981, Manitoba Conservation 1997 unpublished data). However, previous to this study no monitoring has been carried out to determine concentrations of these and other elements in surface soils within the city of Thompson.

In response to the Port Colborne situation and the possible concerns this issue may raise with residents of Thompson, a joint Manitoba Conservation and INCO study was conducted to determine the levels of Ni and other elements in surface soils in the city of Thompson.

SOIL SAMPLING METHODS AND LABORATORY ANALYSIS

Sixty-two sites within the city of Thompson were sampled on September 26 and 27, 2001. The sites were distributed throughout the city and included private residential lots, vacant lots, schoolyards, and playgrounds (Figure 1 and Table 1). Sampling in the city's core business and retail area (downtown) was avoided because of the potential for contamination from other sources within this area.

Soil samples were extracted from the top 2 cm of the soil profile using a small diameter (1.5 cm) soil coring tool (Figure 2). To ensure that an adequate amount of material was available for analysis, each replicate sample was a composite of 20 cores. The cores were extracted at

5 cm intervals along a one metre line (edge of a metre ruler). The metre rule was placed at five random locations on the ground at each sample site to yield five replicate samples per site. The cores for each sample were placed directly into pre-labeled plastic bags (Figure 2).

Table 1. Sites sampled in Thompson, September 2001.

Site Type	Number of Sites Sampled
commercial	1
schoolyard	6
vacant land	7
playground/park	16
residential	32
Total	62

The entire contents of each bag represented a single sample and as such it was imperative that the soil cores in each sample bag be mixed thoroughly into a homogeneous mixture prior to subsampling for laboratory analysis. This involved drying and disaggregating the entire sample, followed by homogenization or mixing, and finally extracting a subsample for analysis. Initially, three of the replicate samples were submitted for measurement of soil pH and analysis for other elements. Unfortunately the first batch of samples that were submitted for analyses were not thoroughly disaggregated and the entire sample was not homogenized during the sample preparation procedure. Instead, a small portion (usually just a few soil cores) of the original composite sample was randomly extracted and subjected to drying, disaggregation, and analysis. Since the soil cores within a given sample often varied in texture, density, and particle size, it was believed that the preparatory procedure used on these samples could have significantly biased the analytical results. Therefore, the results from the initial analysis (*i.e.* the three replicate samples) were rejected, and the remaining two replicate samples were subsequently analyzed.

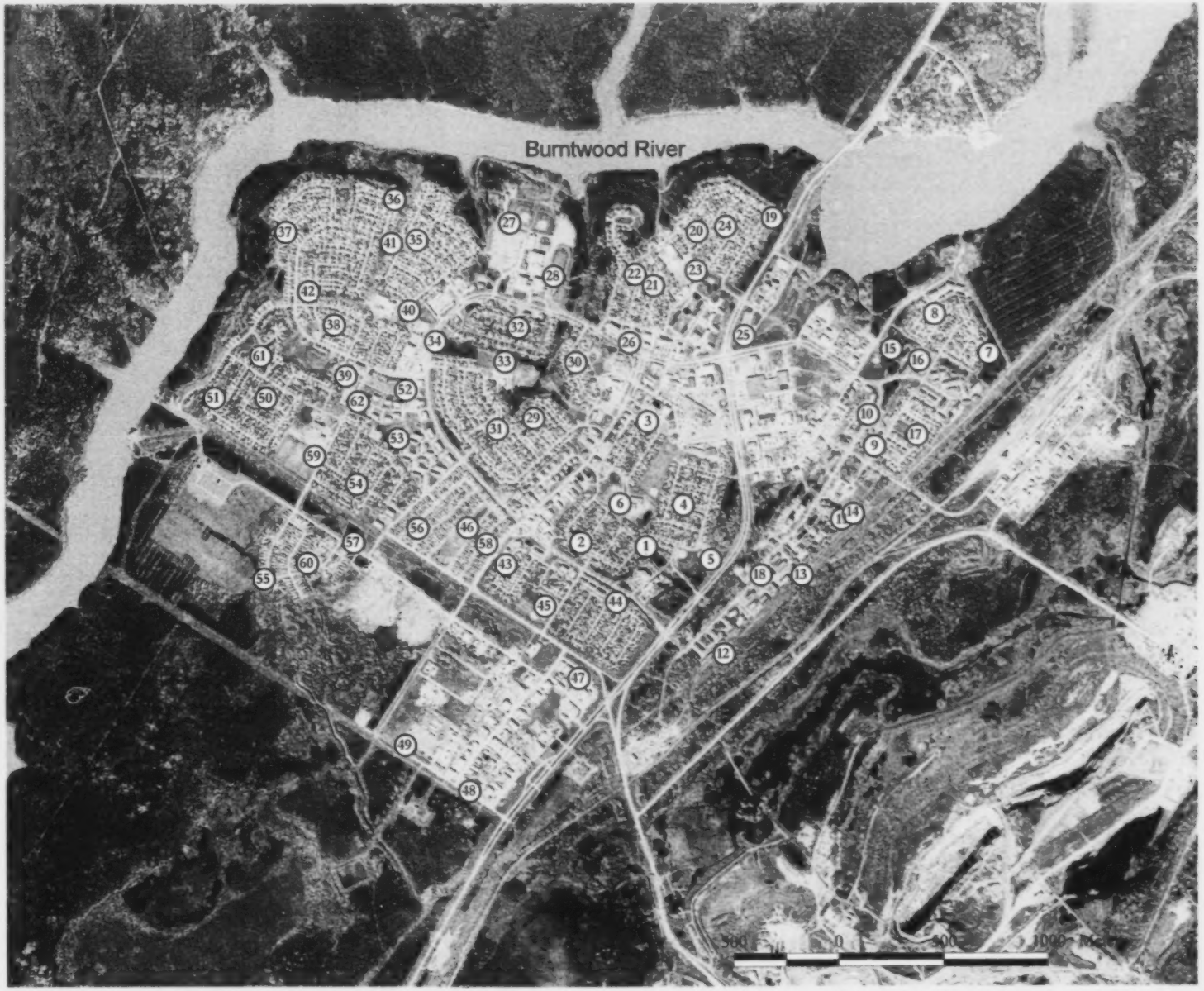

Figure 1. Aerial photograph of Thompson, MB, showing the location of sample sites (labeled with numbers).

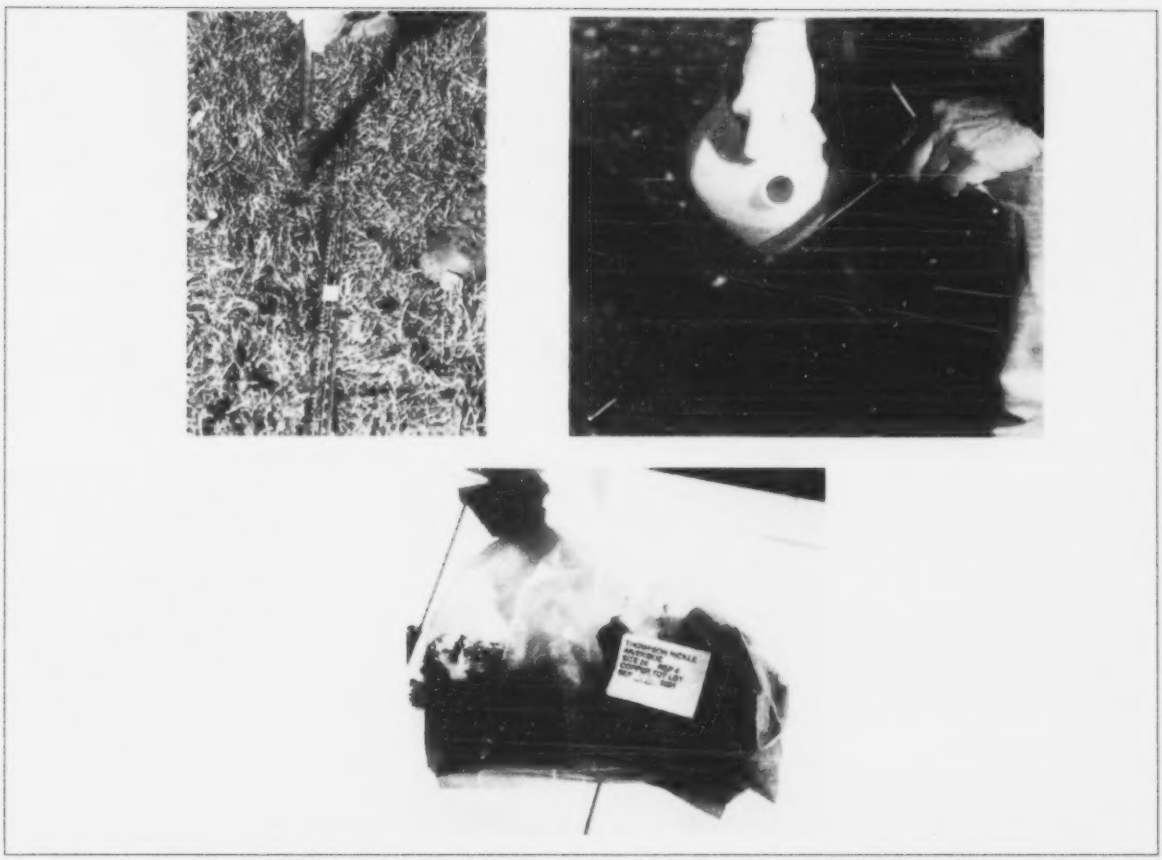

Figure 2. Photographs of soil sampling. Clockwise from upper left: (a) sampling using a small diameter soil coring tool; (b) rinsing equipment with distilled water between sample sites; (c) a replicate sample.

Soil pH was determined by placing the probe of a pH meter in a 2:1 water:soil saturated paste extract. Analyses for most metals involved strong-acid (HCl and HNO_3) digestion of a subsample of soil followed by inductively coupled argon plasma spectroscopy (ICAP). Analysis for cadmium (Cd) was performed using flame atomic absorption spectrophotometry on a strong-acid digested subsample, while analysis for mercury (Hg) was conducted on a digested subsample using cold vapour atomic fluorescence. Analysis for selenium (Se) was performed on a digested subsample using graphite furnace atomic absorption spectrophotometry. Table 2 lists the metals and other elements that were analyzed.

Table 2. List of elements analyzed in surface soil samples collected in Thompson, September 2001. Units are µg/g (equivalent to ppm).

Element	Symbol	Detection Limit	Element	Symbol	Detection Limit
Aluminum	Al	10	Mercury	Hg	0.001
Antimony	Sb	10	Molybdenum	Mo	4
Arsenic	As	10	Nickel	Ni	2
Barium	Ba	1	Phosphorus (as PO_4^-)	P	20
Beryllium	Be	1	Potassium	K	10
Boron	B	1	Selenium	Se	3
Cadmium	Cd	0.3	Silver	Ag	2
Calcium	Ca	1	Sodium	Na	5
Chromium	Cr	2	Strontium	Sr	1
Cobalt	Co	1	Tin	Sn	5
Copper	Cu	1	Titanium	Ti	1
Iron	Fe	2	Vanadium	V	1
Lead	Pb	5	Zinc	Zn	1
Magnesium	Mg	0.1	Zirconium	Zr	1
Manganese	Mn	1			

RESULTS AND DISCUSSION

Soil Quality Guidelines

Canadian soil quality guidelines have been established for a number of trace metals found in soil (CCME 1999). The guidelines are scientifically defensible, numerical limits that were developed to protect both environmental and human health within four main classes of land use: (1) agricultural; (2) residential/parkland; (3) commercial; and (4) industrial (CCME 1999). Guidelines for human health and for environmental health can differ depending on the chemical or element in question and the type of land use involved. The recommended CCME guideline for a substance in soil is always the lower of the two for each of the four land use categories (CCME 1999). For example, if the intended land use of an area is agricultural, and the human health guideline for a given chemical/element in soil intended for agricultural use is 15 µg, and the guideline for environmental health is 10 µg/g, the recommended CCME guideline for that chemical or element in agricultural soil would be 10 µg/g.

The quality of the soil sampled in Thompson has been assessed in this report by comparing the analytical results to the recommended CCME guidelines. It must be stressed that these guidelines are for general purposes only and site-specific conditions should be considered in the application of these values.

Data from replicate soil samples 4 and 5 were used to calculate mean concentrations for each element at each site. Simple summary statistics, as well as the number of sites exceeding the recommended soil quality guideline, were then calculated using these mean values. Since guidelines have not yet been derived for all of the elements analyzed, only those elements (all of which were metals) that currently have a guideline are included in this assessment. The mean concentration (n=4) of metals in surface soil samples collected in August 2001 from a forested site near Orr Lake (approximately 56 km northeast of Thompson) were also included for comparison purposes. Presumably the Orr Lake site is not affected by smelter emissions from Thompson, and as such the concentration data at the site represents ambient or background levels for these metals in soil. The full set of laboratory analysis results for replicate samples 4 and 5 are presented in the Appendix section of this report.

Concentrations of Nickel

According to the CCME (1999) there are not enough data available to derive a soil quality guideline for Ni specifically for the protection of human health. Therefore, the soil Ni concentration recommended for the protection of environmental health has been adopted as the soil quality guideline. This soil Ni guideline is 50 μg/g and applies to all four land use categories. The guideline is specific to soil contact and is based on research that documents the negative effects of elevated Ni on microbial activity and nutrient cycling in the soil, and on the growth and development of plants and soil invertebrates (CCME 1999).

Recently, a health risk assessment was conducted to determine the concentrations of Ni in soil at Port Colborne, ON, that may pose a risk to human health (Ontario Ministry of the Environment 2002). The assessment concluded that Ni concentrations should be lower than 8,000 μg/g (in the top 30 cm of soil) in order to protect children up to the age of five. Children of

toddler-age were considered the highest risk group since they may ingest more soil through their normal play activities. It was recommended that properties with soil Ni concentrations above 8,000 μg/g should be remediated. The assessment also concluded that this intervention level should not pose an immediate or long-term health risk to individuals above age five, although some individuals may become sensitized to the metal and develop a skin reaction (nickel dermatitis) after prolonged contact to high Ni concentrations in soil.

Nickel was present in all of the soil samples collected at the Thompson sites. Mean concentrations ranged from a low of 15 μg/g at site 9 (a residential lot in the northeast corner of the community) to a high of 299 μg/g at site 57 (a vacant parcel of land in the southwest). The highest mean concentration in Thompson was considerably lower than the levels of Ni reported in soil at Port Colborne (Ontario Ministry of the Environment 2002). Concentrations of Ni in the 0 – 5 cm layer of soil in the Port Colborne study ranged from 46 μg/g to 11,000 μg/g, with 90 % of the samples above 467 μg/g.

The mean concentration of Ni at the Orr Lake site (background) was 19 μg/g. This background concentration was exceeded at all but one of the sites sampled in Thompson. The Ni guideline of 50 μg/g was exceeded at 45 (73%) of the 62 sites sampled (Table 3). This included over 86% of the sites located in vacant lots, 83% of the sites located in schoolyards, 75% of the residential sites, and 56% of the sites located in playgrounds and parks. Although sites exceeding the guideline were relatively common, many of these sites had Ni concentrations only slightly higher than 50 μg/g (*i.e.* less than 100 μg/g). Furthermore, it must be stressed that the guideline value of 50 μg/g is not a human health guideline, but is rather an environmental health guideline aimed at minimizing the effects of Ni on microbes, soil invertebrates, and vegetation.

GIS software (*Arcview 3.2*) was used to overlay the mean Ni concentration data on an aerial photo of the community (Figure 3). The resulting map did not reveal any clear relationship between site location and mean Ni concentration in the surface soil, although higher concentrations tended to be in the southern part of the city, which is closer to the smelter. This and the fact that Ni levels were elevated and relatively widely distributed in surface soil across the community implies that emissions from the INCO Ltd. smelter are the main source of Ni in the surface soils in Thompson.

The variability in mean concentrations of Ni between sites is likely related to a combination of factors. Nickel tends to be more mobile in acidic soils than in neutral or basic soils (CCME 1999). This increased mobility can result in increased availability for uptake by vegetation as well as the potential for downward movement of the metal from the upper to the lower soil horizons. The mean soil pH at the Thompson sites ranged from 5.0 to 7.45 and this variation may account for some of the differences in Ni concentrations observed between sites. Nickel also has a tendency to bind to organic molecules in the soil, such that soils that are high in organic matter content accumulate more Ni than soils that are low in organic matter (CCME 1999). Thus, the variation in Ni concentrations between sites may be partially attributable to differences in organic matter content between sites. The length of time a soil has been exposed to smelter emissions strongly influences the amount of metal that accumulates in the soil. More recently landscaped sites would have lower Ni concentrations than sites that were landscaped at an earlier time because of a shorter time period for accumulation to occur. As well, the source of the fill material and topsoil or sod used in landscaping could influence the amount of Ni present at each site. If these materials were of local origin then the surface soil could potentially have a higher concentration of Ni than if the materials originated from outside the area where smelter emissions have been deposited.

Based on the risk assessment done at Port Colborne, the human health risk from exposure to Ni in the surface soils in Thompson is considered to be extremely low. Humans are exposed to Ni in soil through soil ingestion, dermal contact with soil, and eating garden produce that may contain Ni. Although no gardens were sampled in Thompson during this survey, garden soil can be expected to have lower metal concentrations than surface soil in lawns because gardening activities incorporates any deposited metals thoroughly into the 15 cm to 20 cm layer, thus diluting the concentration. Regardless of the extremely low human health risk from Ni in Thompson soil, it is always wise to wash hands after working or playing in soil and to thoroughly wash all garden produce prior to eating.

Table 3. Mean concentrations of Ni in surface soil samples collected from 62 sample sites in Thompson, September 2001. Sites in bold font exceeded the soil guideline for Ni (50 µg/g). (n = 2, S.D. = standard deviation)

Sample Site	Site Type	Ni (ug/g)	S.D.	Sample Site	Site Type	Ni (ug/g)	S.D.
46	playground/park	34	1	9	residential	15	1
5	playground/park	36	7	19	residential	26	18
15	playground/park	37	2	50	residential	35	5
24	playground/park	39	23	8	residential	36	17
23	playground/park	39	7	35	residential	41	2
61	playground/park	41	4	3	residential	47	1
26	playground/park	42	13	22	residential	49	4
41	**playground/park**	**52**	18	31	residential	49	26
17	**playground/park**	**55**	7	**11**	**residential**	**51**	4
45	**playground/park**	**59**	11	**51**	**residential**	**56**	18
60	**playground/park**	**67**	4	**30**	**residential**	**57**	2
27	**playground/park**	**72**	9	**7**	**residential**	**61**	27
34	**playground/park**	**80**	23	**4**	**residential**	**63**	21
42	**playground/park**	**97**	16	**18**	**residential**	**68**	8
16	**playground/park**	**108**	8	**32**	**residential**	**68**	4
25	**playground/park**	**147**	38	**36**	**residential**	**73**	29
				12	**residential**	**73**	14
33	schoolyard	41	2	**53**	**residential**	**74**	8
28	**schoolyard**	**67**	11	**10**	**residential**	**79**	12
14	**schoolyard**	**86**	38	**20**	**residential**	**79**	11
6	**schoolyard**	**89**	4	**38**	**residential**	**81**	4
59	**schoolyard**	**147**	28	**54**	**residential**	**87**	26
40	**schoolyard**	**164**	37	**37**	**residential**	**93**	24
				29	**residential**	**101**	23
55	vacant land	43	4	**43**	**residential**	**101**	31
62	**vacant land**	**58**	3	**39**	**residential**	**115**	22
58	**vacant land**	**64**	0	**13**	**residential**	**121**	3
52	**vacant land**	**78**	-	**1**	**residential**	**149**	52
49	**vacant land**	**131**	11	**21**	**residential**	**149**	120
47	**vacant land**	**212**	51	**2**	**residential**	**154**	14
57	**vacant land**	**299**	59	**44**	**residential**	**179**	7
				56	**residential**	**218**	4
48	**commercial**	**252**	5				

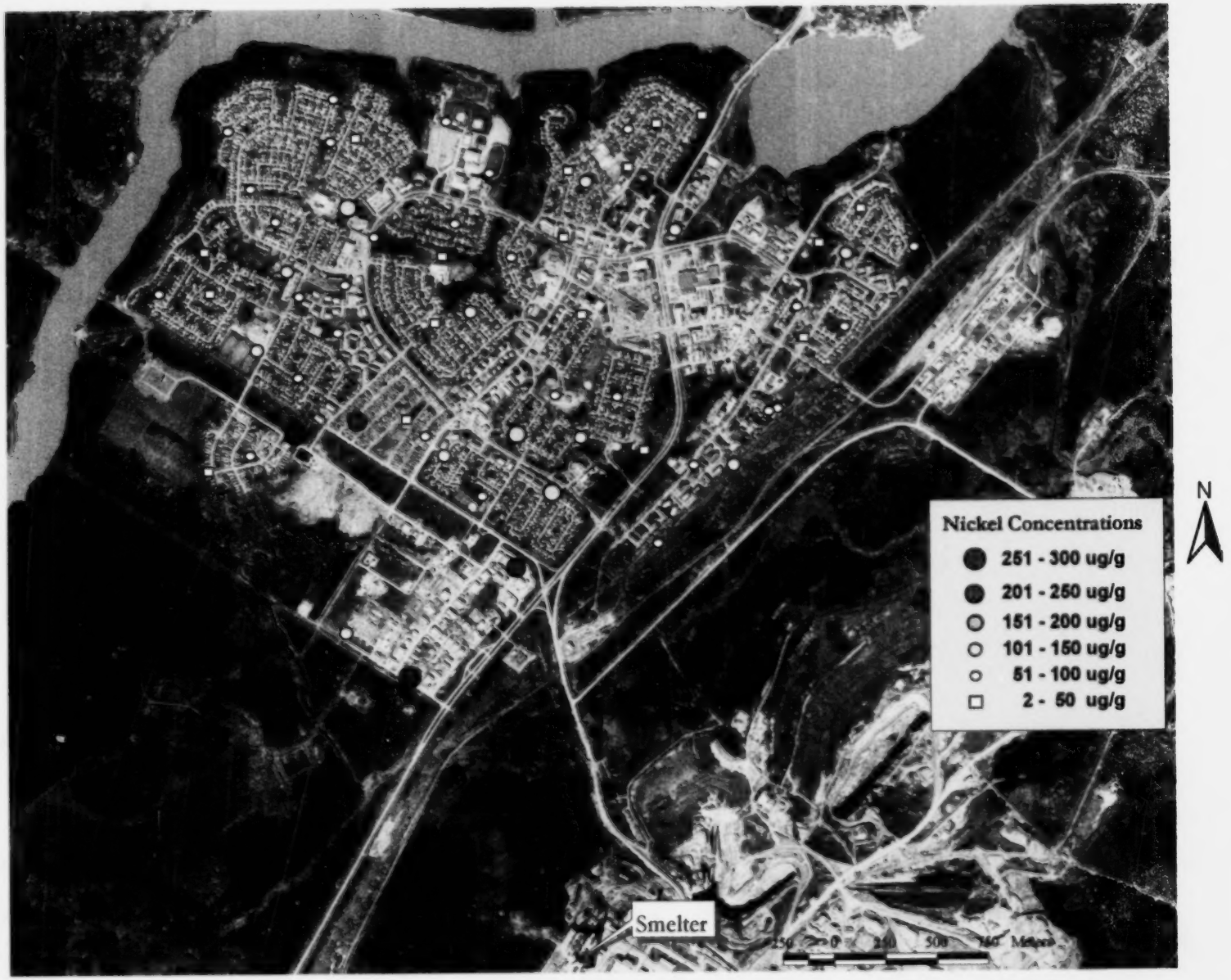

Figure 3. Aerial photograph of Thompson, MB, showing the ranges in Ni concentration in surface soil samples collected at 62 sample sites.

Concentrations of Other Metals

In addition to Ni, soil quality guidelines have also been developed for barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), vanadium (V), and zinc (Zn). Summary statistics for these metals are presented in Table 4.

Cadmium was detected (≥0.3 µg/g) in samples collected from 44 (71%) of the sites sampled (Table 4). Mean detectable concentrations ranged from 0.4 µg/g to 2.5 µg/g. Although 14 sites had mean concentrations above the guideline of 1.4 µ/g for soil intended for agricultural purposes, concentrations at all the sites were well below the guideline of 10 µg/g for residential and parkland use. The majority of sites that exceeded the agricultural guideline were located in the northeast area of the city (Figure 4). The reason for the variation in concentration and distribution of Cd across the community is not known. Although Cd has been detected in the smelter emissions, amounts are very low, especially in comparison to the quantities of Ni and Cu that are emitted (MAC 2002). As well, results from past monitoring of forested sites in the vicinity of Thompson (Phillips 1981 and Manitoba Conservation unpublished data 1997) showed that Cd was not elevated in surface soils and was not correlated with concentrations of Ni and Cu. In light of these facts the elevated levels of Cd in the soils collected from Thompson in 2001 must have originated from a source(s) other than the smelter.

Table 4. Summary of metal concentrations (Ni excluded) in surface soil samples collected from 62 sampling sites in Thompson, September 2001. Units are µg/g (equivalent to ppm).

Metal	Mean	Range		Number of Sites Exceeding Guidelines*				Orr Lake
		Min	Max	Agricultural	Residential/Parkland	Commercial	Industrial	Results
Ba	47	17	99	0 (750)	0 (500)	0 (2000)	0 (2000)	49
Cd**	1.1	0.4	2.5	14 (1.4)	0 (10)	0 (22)	0 (22)	< 0.3
Cr	24	9	67	1 (64)	1 (64)	0 (87)	0 (87)	13.3
Co	12	1.5	99	2 (40)[†]	1 (50)[†]	0 (300)[†]	0 (300)[†]	2.3
Cu	23	7	67	1 (63)	1 (63)	0 (91)	0 (91)	7
Pb	28	7	279	2 (70)	2 (140)	1 (260)	0 (600)	< 30
Hg	0.045	0.004	0.149	0 (6.6)	0 (6.6)	0 (24)	0 (50)	0.095
V	13	5	27	0 (130)	0 (130)	0 (130)	0 (130)	9
Zn	43	12	198	0 (200)	0 (200)	0 (360)	0 (360)	23

* Guidelines are in parentheses

** Based only on sites where Cd was present at detectable concentrations (n = 44)

† Remediation criteria

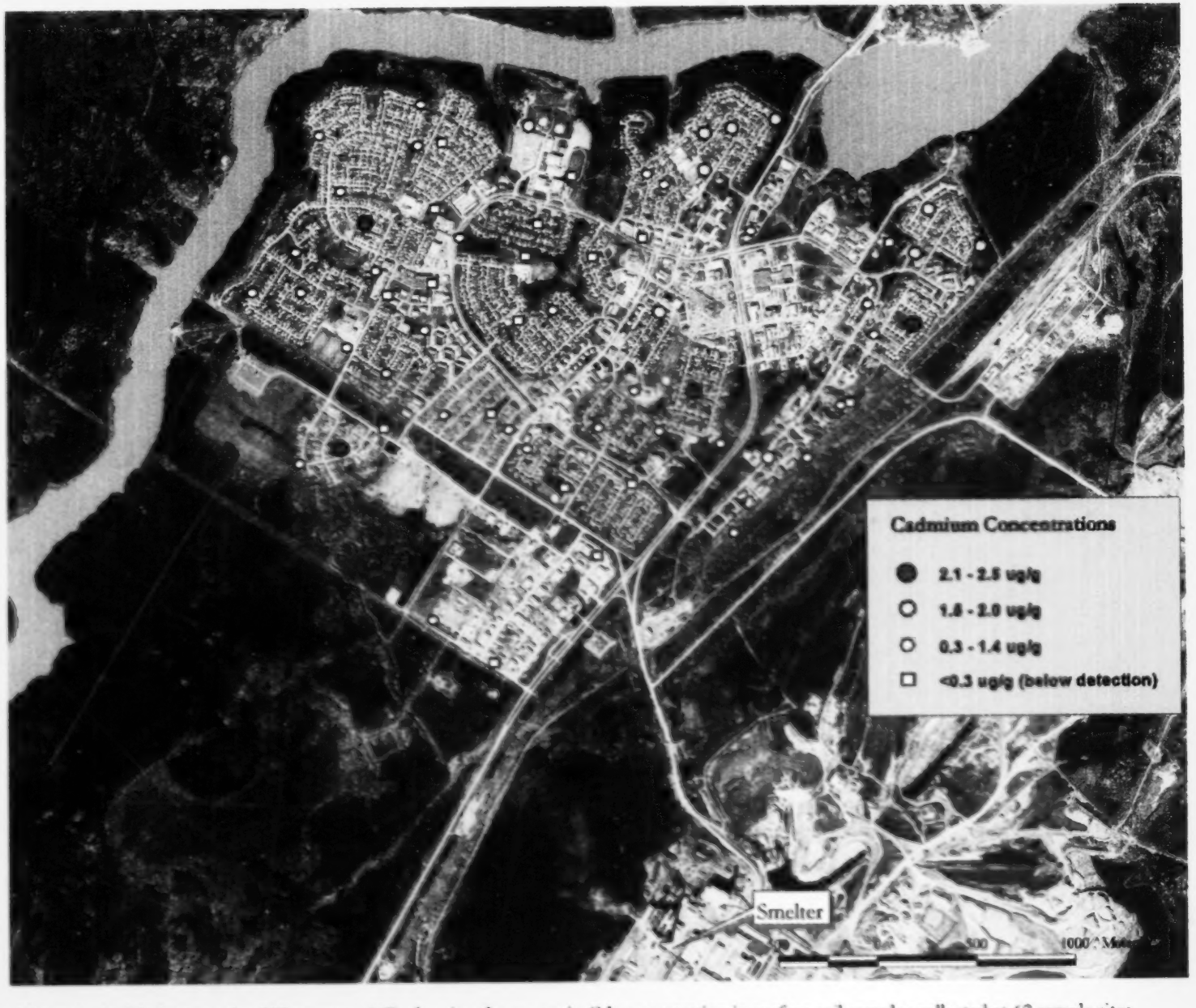

Figure 4. Aerial photograph of Thompson, MB, showing the ranges in Cd concentration in surface soil samples collected at 62 sample sites.

Research has shown that Cd can enter the human body via ingestion of plant material or by eating meat from livestock or wildlife that have consumed vegetation that contains Cd (CCME 1999). Uptake of Cd by plants is dependent on the plant species involved, the concentration of the element in soil, and the chemistry of the soil (CCME 1999). Once in the body, Cd can accumulate in the kidneys and liver and can cause health problems. Because the soil-plant-human pathway creates a potential health risk, CCME (1999) has recommended that site specific objectives, such as adoption of the agricultural use guideline (1.4 μ/g), be considered where produce gardens are being planted in residential/parkland areas. Within Thompson, the pathway of interest is consumption of garden produce that may have taken up Cd from the soil. However, as stated previously, garden soils usually have lower metal concentrations than turf soils because tilling of the garden mixes and dilutes the surface residues in a large volume of soil. Another mitigating factor is that Thompson's climate is not conducive to growing large crops of garden produce and therefore the dietary intake by residents would be relatively low. Finally, given the above, and since concentrations in the 14 sites with elevated Cd are only slightly higher than the agriculture use guideline, it is believed that the risk of human health effects from the Cd in Thompson soils is very low.

Levels of Cr at the Thompson sites were moderately elevated above the background levels at the Orr Lake site (Table 4). Mean concentrations of Cr at the Thompson sites ranged from 9 to 67 μg/g. The guideline for Cr in soil intended for agricultural and residential use (64 μg/g) was slightly exceeded at a single site located on vacant land near the corner of Campbell and Weir. The Cr guideline is intended to protect environmental health and is based on the negative impact Cr has on microbial organisms and subsequent effects on organic decomposition in the soil (CCME 1999). There is no concern that these concentrations of Cr might cause health effects.

Concentrations of Cu at the Thompson sites were moderately elevated above the background levels at the Orr Lake site (Table 4). Mean concentrations of Cu in this study ranged from 7 to 67 μg/g. The guideline for Cu in soil intended for agricultural and residential use (63 μg/g) was exceeded by a slight amount at a single site. This site, a vacant lot, was located at the intersection of Walleye and Johnston. Copper is considered essential for the normal growth and development of most living organisms. However, only very small amounts are required, and

high concentrations of the element in the environment can have a toxic effect on both plants and animals (CCME 1999). The guideline for Cu in soil for agricultural and residential use is intended to protect human health and is based on the possible toxic effects of long term exposure through soil ingestion (CCME 1999). There is little risk of humans ingesting significant quantities of soil from a lawn and the soils in gardens would normally have lower concentrations of metals (see discussion on Cd). In light of this and since all but one site had concentrations of Cu below the guideline, there is no concern that Cu concentrations in the Thomson soils might cause health effects.

Mean concentrations of Pb ranged from 7 to 279 μg/g. Most of the sites (76%) had mean concentrations of Pb below 30 μg/g, which is comparable to the results reported for the Orr Lake site. All sites except two had soil concentrations below the agricultural use guideline of 70 μg/g. One of the exceptions was a vacant lot at the intersection of Eider and Ospwagan, which had a mean concentration of 279 μg/g and thus exceeded the guidelines for all land uses. The other exception was the Southwood Park site, with 223 μg/g, which exceeded the agricultural and residential/parkland land use guidelines of 70 and 140 μg/g, respectively. The guideline for Pb in soil intended for agricultural use (70 μg/g) is based on studies which found that there were adverse effects of lead uptake/ingestion on plants and soil invertebrates, and on mammalian and bird species further up the food web (CCME 1999). The soil guideline for residential/parkland land use (140 μg/g) is a human health guideline and is based on research into potential health risks resulting from ingestion of soil containing Pb.

It should be noted that Pb concentrations varied considerably between replicate samples at both the Eider/Ospwagan and Southwood Park sites. One of the replicate samples at the Eider/Ospwagan site had a Pb concentration of 539 μg/g, while the other replicate had a concentration of only 19 μg/g. At the Southwood Park site one replicate had a concentration of 434 μg/g compared with only 12 μg/g at the other. This high degree of variation between replicates was not observed in other metals at these sites, which suggests that the high Pb concentrations in the two replicates were likely anomalies and probably originated from a source unrelated to the smelter emissions (*e.g.* chips of lead based paint).

If the source was Pb in paint chips, that Pb when mixed into the soil is typically not available for uptake by plants and the risk of ingestion by humans is also minimal. It should also be noted that these results are based on the analyses of lawn soils and the risk of ingestion of that soil is relatively low. The risk of exposure to humans would be higher if these were garden soils (direct contact with soil and possible uptake by plants intended for human consumption). However, as per the discussion for other metals, the concentrations in gardens are expected to be much lower because the Pb will be mixed in a large volume of soil and thus diluted. Therefore the risk that the Pb in Thompson soils might cause health effects is extremely low.

Mean concentrations of Ba, Hg, V, and Zn were below guideline levels at all the Thompson sites sampled (Table 4). The guideline for Ba in soil varies from 500 to 2000 μg/g depending on the intended land use. Mean concentrations of Ba ranged from 17 to 99 μg/g and as such were well below guideline levels. The overall mean level for Ba at the Thompson sites was 47 μg/g, which was very similar to the mean level recorded at the Orr Lake site. Mean levels of Hg at the Thompson sites ranged from 0.004 to 0.149 μg/g, which are also well below guideline levels. This, and the fact that the mean level of Hg at the Orr Lake site was in the upper portion of this range, implies that the trace amounts of Hg in the soils in Thompson are likely of natural origin. Concentrations of V ranged from 5 to 27 μg/g and, as with Ba and Hg, were considerably lower than the recommended guidelines for all land uses. Mean levels of Zn in Thompson soils ranged from 12 μg/g to 198 μg/g, with almost half (44%) of the sites reporting levels above those of the Orr Lake site. Although these results suggest that mean levels of Zn may be elevated at some sites, none exceeded guideline levels for the metal. Because concentrations of Ba, Hg, V, and Zn were below guideline levels in the Thompson soils, there is no concern that they might cause environmental or human health effects.

Most of the Thompson sites (>90%) had mean concentrations of the metal cobalt (Co) above the mean concentration of 2.3 μg/g recorded at the Orr Lake site. Since Co is a known component of the INCO smelter emissions, the elevated levels of this metal in the community are probably the result of deposition of smelter particulates. This is consistent with the results of a past study which found that Co concentrations were generally above ambient levels in the

vicinity of the smelter complex and declined to background levels with increasing distance from the smelter (Phillips 1981).

Although there are currently no soil quality guidelines for Co, there are interim soil quality criteria. Interim soil quality criteria are numerical limits for contaminants in soil that are intended to provide protection and maintenance of environmental and human health at contaminated sites (CCME 1991). There are two types of soil quality criteria: assessment criteria and remediation criteria. Assessment criteria are numerical values that approximate the background or ambient concentrations of substances in soil. If the concentration of a substance in the soil does not exceed its assessment criterion, then the soil is considered uncontaminated and no environmental or human health risk exists. Remediation criteria are numerical values that can be used as a basis for further investigation of a potentially contaminated site or remediation of an identified contaminated site. As with the soil quality guidelines, the remediation criterion for a specific contaminant in soil may differ depending whether the land use is agricultural, residential/parkland, or commercial/industrial. The degree to which the remediation criteria are exceeded can be used to gauge the urgency of the problem and help one decide what type of action needs to be taken. As well, the remediation criteria can be used to identify land use restrictions. It is important to keep in mind that these criteria are only for interim guidance.

Mean concentrations of Co were above the assessment criterion of 10 μg/g (CCME 1991) at 19 (30%) of the sites sampled in Thompson. The interim remediation criteria for Co in soil intended for agricultural use and residential/parkland use are 40 μg/g and 50 μg/g, respectively (CCME 1991). The vacant lot site located at the intersection of Campbell and Weir had a mean Co concentration of 99 μg/g and thus exceeded both criteria. Another site located at the Westwood School sports field had a mean concentration of 42 μg/g, which slightly exceeded the remediation criterion for agricultural land use. Because of the safety factors built into these interim criteria and the lack of evidence that these levels might cause human health effects, it is believed that the risk to human health posed by the levels of Co in Thompson soils is extremely low.

Several of the elements analyzed as part of this survey were found to be below the laboratory detection limit at all or most of the sites sampled. These included antimony (Sb), arsenic (As), molybdenum (Mo), selenium (Se), tin (Sn), beryllium (Be) (except a single sample at site 57 which was 2.5 µg/g), and silver (Ag) (except for samples at sites 25, 54, and 55, which ranged between 4 and 6 µg/g). Here again there is no concern for environmental or health effects from these elements.

SUMMARY AND RECOMMENDATIONS

Replicate surface soil samples were collected at 62 different locations in Thompson, Manitoba, in September 2001 and analyzed for metal and metalloid content. Sites sampled included one commercial property, six schoolyards, seven vacant lands, 16 city parks and playgrounds, and 32 residential properties. The analytical results were assessed using existing Canadian soil quality guidelines (CCME 1999) and interim remediation criteria (CCME 1991).

The soil quality guideline for Ni is intended for protection of the environment and is based primarily on the negative impacts of Ni on soil invertebrates and vegetation. This guideline of 50 µg/g (the same for all land uses) was exceeded at 45 of the 62 sites sampled. Sites that exceeded the guideline were distributed throughout the city, with the highest values recorded in the southern portion of the community.

The highest mean concentration of Ni at the Thompson sites was 299 µg/g, which was considerably lower than the levels of Ni reported in soil at Port Colborne, ON (Ontario Ministry of the Environment 2002). Concentrations of Ni in the 0 – 5 cm layer of soil in the Port Colborne study ranged from 46 µg/g to 11,000 µg/g, with 90 % of the samples above 467 µg/g. A health risk assessment, conducted as part of the Port Colborne investigation, concluded that there was minimal risk to human health (particularly young children) if the concentration of Ni in the soil was lower than 8,000 µg/g.

Mean concentrations of Cr and Cu were generally low at the sites sampled in Thompson, but did exceed soil quality guidelines at a single site. Lead concentrations were also generally low across the city with the exception of two locations – a vacant lot and a city park -- where mean concentrations exceeded recommended guidelines for residential/parkland and agricultural uses. Cadmium was above detection limits at 44 of the sites sampled and mean concentrations exceeded the agricultural use guideline at 14 of these sites. The human health guideline for residential/parkland use, however, was not exceeded at any of the sites sampled.

Based on the risk assessment done for Port Colborne, the risk of human health effects from exposure to the Ni in the surface soils in Thompson is considered to be extremely low. Similarly, the risk of human health effects from the other metals found in Thompson soils is also considered to be extremely low. Although the human health risk associated with exposure to Thompson soils is considered negligible, it is always wise to wash hands after contact with the soil and to thoroughly clean garden produce prior to eating.

REFERENCES

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The following was inadvertently omitted from the REFERENCES section.

Wotton, D. L. and G. D. Hogan. 1981. The effects of atmospheric emissions from the Thompson mining and smelting industry on forest vegetation and soils. Submission to the Clean Environment Commission, Province of Manitoba. Environmental Standards and Studies Section, Manitoba Department of Consumer and Corporate Affairs and Environment. Winnipeg, MB. 112 pp.

Element concentrations in replicate soil samples collected at 62 sites in Thompson, MB and at the Orr Lake site, 58 km northeast of Thompson.

Sample	Site	Rep	pH	Sb	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Ag	Sn	V	Zn	Al	B	Ca	Fe	Mg	Mn	PO4	K	Na	Sr	Ti	Zr
1	4	6.6	<10	<10	44	<1	1	38	36	25	38	0.067	<4	185	<3	<2	<5	10	62	4170	10	10200	22200	5490	97	3270	1240	404	18	98	3
1	5	6.2	<10	<10	39	<1	1.2	19	7	20	13	0.072	<4	112	<3	<2	<5	8	58	2450	55	12100	6480	3870	91	4380	1060	107	12	64	<1
2	4	5.7	<10	<10	50	<1	0.9	29	8	36	61	0.112	<4	164	<3	<2	<5	16	34	6280	6	13600	12500	3520	113	2720	961	95	14	163	4
2	5	6.5	<10	<10	42	<1	0.9	28	8	30	63	0.058	<4	144	<3	<2	<5	14	25	5240	3	6910	12100	4590	113	1810	870	122	11	178	3
3	4	6.5	<10	<10	78	<1	1.8	17	5	12	19	0.045	<4	48	<3	<2	<5	13	44	4140	6	13800	9990	4280	167	2890	1010	54	22	22	3
3	5	6.7	<10	<10	57	<1	1.2	17	5	10	13	0.038	<4	46	<3	<2	<5	11	34	3710	4	11100	9000	4250	140	2100	920	64	18	29	2
4	4	4.7	<10	<10	35	<1	2.6	32	4	19	24	0.164	<4	78	<3	<2	<5	16	87	2250	27	11700	7210	1350	49	4480	409	75	15	43	<1
4	5	5.7	<10	<10	28	<1	1.7	22	2	13	21	0.099	<4	48	<3	<2	<5	10	74	2070	42	11700	4800	2860	71	2390	529	45	14	44	<1
5	4	6.5	<10	<10	43	<1	1.1	15	3	9	12	0.022	<4	41	<3	<2	<5	11	24	3540	3	17400	6530	4080	103	2010	739	45	17	41	2
5	5	6.8	<10	<10	32	<1	0.9	15	2	6	12	0.018	<4	31	<3	<2	<5	10	17	2910	25	17300	5590	4100	86	1230	597	37	16	45	1
6	4	7	<10	<10	41	<1	0.6	25	4	19	23	0.018	<4	92	<3	<2	<5	15	27	5660	7	15700	11800	6510	143	928	1550	99	14	242	4
6	5	6.9	<10	<10	37	<1	0.7	27	3	17	19	0.015	<4	86	<3	<2	<5	13	23	5090	4	13500	10500	6500	127	857	1420	80	17	209	4
7	4	6.6	<10	<10	43	<1	1.4	31	2	11	18	0.04	<4	42	<3	<2	<5	15	41	5460	5	18400	9750	5680	140	2390	1010	82	17	181	4
7	5	6.3	<10	<10	44	<1	2.4	44	6	19	46	0.072	<4	80	<3	<2	<5	14	72	4300	56	10600	10000	3980	112	2660	832	104	14	142	1
8	4	5.6	<10	<10	31	<1	1.7	17	2	12	17	0.09	<4	48	<3	<2	<5	8	19	2720	<1	15700	3750	9410	93	2490	738	30	16	44	<1
8	5	6.2	<10	<10	34	<1	1.4	13	<1	7	13	0.043	<4	24	<3	<2	<5	9	18	3650	1	19000	4900	11000	135	2000	794	46	18	68	2
9	4	6.6	<10	<10	81	<1	0.9	9	2	7	14	0.047	<4	14	<3	<2	<5	10	35	4380	9	9500	7400	3130	137	1710	1040	69	32	13	6
9	5	6.9	<10	<10	69	<1	0.9	8	2	7	12	0.045	<4	16	<3	<2	<5	9	34	3480	10	10100	7180	3070	160	1550	974	81	28	10	5
10	4	6	<10	<10	83	<1	1	25	5	17	27	0.086	<4	70	<3	<2	<5	17	45	8280	8	14200	13400	4670	131	2420	1360	167	31	209	8
10	5	6.6	<10	<10	56	<1	0.9	27	13	14	33	0.049	<4	87	<3	<2	<5	14	46	5820	30	9090	15900	4330	108	2430	1230	267	20	156	4
11	4	7.4	<10	<10	27	<1	0.6	19	3	11	12	0.011	<4	53	<3	<2	<5	10	16	3600	3	11400	7070	4670	100	884	1020	75	11	178	3
11	5	7.5	<10	<10	24	<1	0.5	16	3	9	13	0.013	<4	48	<3	<2	<5	9	12	2970	45	7620	6090	3250	73	804	758	70	9	143	2
12	4	7.4	<10	<10	78	<1	0.6	30	7	17	27	0.018	<4	83	<3	<2	<5	23	40	11500	12	23100	18900	10000	230	960	3080	208	26	353	10
12	5	7	<10	<10	42	<1	0.6	23	3	23	19	0.015	<4	63	<3	<2	<5	15	35	5970	7	18100	12600	6340	172	756	1590	105	17	254	5
13	4	6.3	<10	<10	82	<1	0.9	21	8	29	32	0.108	<4	123	<3	<2	<5	19	55	7260	12	15600	11800	4110	122	2280	2280	155	18	91	8
13	5	6.2	<10	<10	77	<1	1	19	7	26	30	0.076	<4	119	<3	<2	<5	20	61	6960	9	14200	11300	3230	104	2480	1740	60	16	29	9
14	4	6.7	<10	<10	35	<1	<3	15	6	18	16	0.058	<4	113	<3	<2	<5	8	32	3050	14	11900	6170	3370	213	2700	1070	121	26	100	3
14	5	7.2	<10	<10	32	<1	<3	15	10	8	10	0.034	<4	59	<3	<2	<5	7	16	2670	29	11200	8340	3620	137	1350	790	207	26	80	3
15	4	7.4	<10	<10	24	<1	<3	16	3	9	10	0.022	<4	38	<3	<2	<5	8	15	2670	44	9470	5250	3100	88	1300	725	121	14	111	1
15	5	6.9	<10	<10	19	<1	<3	12	1	7	10	0.031	<4	35	<3	<2	<5	8	18	2050	6	18700	4350	2510	84	1450	629	60	10	118	2
16	4	6.9	<10	<10	39	<1	2.3	29	11	54	42	0.067	<4	102	<3	<2	<5	12	31	4070	5	10200	11100	3880	93	2420	706	141	18	132	3
16	5	6.7	<10	<10	48	<1	1	31	14	46	64	0.121	<4	113	<3	<2	<5	14	37	4780	5	15500	14000	3840	102	3290	1090	199	18	154	4
17	4	7	<10	<10	31	<1	2.2	21	2	11	12	0.013	<4	50	<3	<2	<5	10	17	2880	3	9360	5660	4730	79	1760	869	69	11	163	1
17	5	6.7	<10	<10	34	<1	2.2	18	4	14	11	0.027	<4	60	<3	<2	<5	9	16	2520	8	15800	5480	3710	82	1670	969	79	10	125	2
18	4	6.7	<10	<10	32	<1	1.8	21	3	16	26	0.015	<4	73	<3	<2	<5	13	25	4130	4	12500	8740	5750	86	1470	1240	114	12	180	2
18	5	7.7	<10	<10	23	<1	1.8	19	3	15	23	0.011	<4	62	<3	<2	<5	10	19	3130	3	10900	6410	5180	74	1130	829	90	10	141	1
19	4	7	<10	<10	19	<1	1.4	5	<1	3	5	0.02	<4	13	<3	<2	<5	3	6	1390	26	10100	2290	1450	49	757	320	22	18	55	1
19	5	6.9	<10	<10	45	<1	1.5	15	<1	10	14	0.041	<4	39	<3	<2	<5	11	23	5470	25	8680	5800	3030	97	1440	849	69	20	146	5
20	4	7.2	<10	<10	67	<1	1.7	26	4	25	22	0.047	<4	71	<3	<2	<5	18	53	9050	5	7280	12900	5750	154	1370	1980	136	18	294	7
20	5	7	<10	<10	78	<1	1.6	28	4	22	25	0.056	<4	87	<3	<2	<5	22	47	10300	10	9460	15200	5820	182	1940	2320	120	22	322	13
21	4	7.1	<10	<10	59	<1	1.4	56	51	29	30	0.099	<4	233	<3	<2	<5	13	46	5530	16	15200	30800	4950	145	3720	1630	533	36	139	9
21	5	7	<10	<10	55	<1	1.3	28	3	16	22	0.05	<4	64	<3	<2	<5	18	38	8310	10	12900	13100	4890	146	1980	1620	110	19	263	9
22	4	7.3	<10	<10	22	<1	1	16	4	10	13	0.034	<4	51	<3	<2	<5	8	29	2430	52	12000	5420	4090	66	1160	393	94	14	99	<1
22	5	7.3	<10	<10	23	<1	1	16	3	10	10	0.029	<4	46	<3	<2	<5	9	35	2670	3	14700	5310	4730	80	1360	371	101	16	115	1
23	4	6.4	<10	<10	17	<1	1.6	12	1	10	8	0.029	<4	44	<3	<2	<5	7	20	1980	32	7060	3570	2240	89	2180	566	45	10	82	<1
23	5	6	<10	<10	16	<1	1.5	12	2	8	9	0.025	<4	34	<3	<2	<5	7	14	1940	26	5200	3270	1700	74	1400	484	42	8	73	<1

Element concentrations in replicate soil samples collected at 62 sites in Thompson, MB and at the Orr Lake site, 58 km northeast of Thompson.

Sample Site	Rep	pH	Sb	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Ag	Sn	V	Zn	Al	B	Ca	Fe	Mg	Mn	PO4	K	Na	Sr	Ti	Zr
24	4	5.5	<10	<10	15	<1	1	11	<1	5	7	0.005	<4	22	<3	<2	<5	7	17	200	6	12100	3820	2030	68	1620	379	41	7	104	2
24	5	4.5	<10	<10	25	<1	2	12	2	12	8	0.052	<4	55	<3	<2	<5	8	24	1520	23	10200	2920	1280	80	2940	499	25	8	58	<1
25	4	4.9	<10	<10	78	<1	0.8	29	16	32	33	0.058	<4	174	<3	6	<5	18	59	7520	46	7230	16900	7080	210	4920	2620	812	17	268	3
25	5	5.6	<10	<10	64	<1	<.3	26	18	30	20	0.046	<4	120	<3	6	<5	18	48	7590	46	8150	17400	5770	233	3440	2470	289	14	264	3
26	4	6.9	<10	<10	46	<1	<.3	18	7	21	27	0.021	<4	51	<3	<2	<5	12	52	5290	33	18600	11300	6450	133	1960	1340	68	15	191	2
26	5	6.7	<10	<10	56	<1	<.3	17	7	17	7	0.019	<4	32	<3	<2	<5	12	38	5870	36	23200	11700	8510	146	2870	1700	452	27	143	2
27	4	7	<10	<10	46	<1	1.8	19	7	18	10	0.035	<4	65	<3	<2	<5	12	47	3030	21	13800	8300	4910	246	3720	1160	5	17	95	2
27	5	6.1	<10	<10	54	<1	1.8	23	10	20	10	0.039	<4	78	<3	<2	<5	15	49	4510	34	12200	11100	5390	199	3800	1410	101	16	167	3
28	4	6.7	<10	<10	26	<1	<.3	17	10	17	7	0.019	<4	75	<3	<2	<5	8	48	3670	23	6280	10700	4800	106	1900	1130	248	9	133	2
28	5	7.1	<10	<10	26	<1	<.3	15	8	14	9	0.023	<4	59	<3	<2	<5	9	32	3680	20	21300	8630	6710	117	2180	1200	<5	14	142	2
29	4	5.8	<10	<10	35	<1	0.8	24	8	25	39	0.104	<4	117	<3	<2	<5	9	48	3460	21	9080	9830	5320	131	2770	785	121	10	110	2
29	5	6.3	<10	<10	30	<1	0.5	24	9	21	21	0.037	<4	85	<3	<2	<5	15	47	4320	34	14900	11800	7240	133	1700	1110	26	12	212	2
30	4	7.1	<10	<10	75	<1	<.3	24	12	35	14	0.027	<4	58	<3	<2	<5	22	46	10900	55	23400	21000	10900	220	1430	2870	285	23	103	2
30	5	7.3	<10	<10	63	<1	<.3	23	11	31	13	0.027	<4	55	<3	<2	<5	20	40	11100	52	24600	19000	12300	195	1170	2670	681	26	100	2
31	4	7.4	<10	<10	64	<1	<.3	8	5	14	51	0.025	<4	30	<3	<2	<5	7	26	3140	19	25000	8610	5790	133	702	966	103	18	71	2
31	5	7.2	<10	<10	49	<1	<.3	19	8	19	86	0.028	<4	67	<3	<2	<5	15	65	7000	41	23500	13800	11300	169	2030	2130	392	21	188	2
32	4	5.7	<10	<10	40	<1	<.3	18	7	19	42	0.187	<4	70	<3	<2	<5	10	31	3540	19	16700	8400	4590	116	2330	1180	119	18	109	2
32	5	6.6	<10	<10	27	<1	<.3	21	6	17	24	0.089	<4	65	<3	<2	<5	10	28	3070	18	14000	7890	5070	104	2250	1160	<5	10	111	2
33	4	7.4	<10	<10	32	<1	<.3	17	7	30	7	0.019	<4	39	<3	<2	<5	12	28	5760	35	66500	11600	9690	173	1370	1270	17	20	167	2
33	5	7.5	<10	<10	25	<1	<.3	19	6	29	7	0.012	<4	42	<3	<2	<5	10	21	4720	32	23600	10700	10100	126	710	959	<5	15	188	2
34	4	7.1	<10	<10	32	<1	<.3	20	7	19	18	0.019	<4	63	<3	<2	<5	11	36	3720	21	14300	9500	5770	110	2710	1220	39	10	167	2
34	5	6.8	<10	<10	35	<1	0.6	18	8	26	27	0.027	<4	96	<3	<2	<5	11	64	3480	21	9720	9140	5320	126	3370	1070	19	9	114	2
35	4	7.4	<10	<10	53	<1	<.3	22	8	29	10	0.039	<4	39	<3	<2	<5	17	43	9550	44	23600	15800	12400	184	1350	2170	509	24	101	2
35	5	6.9	<10	<10	54	<1	<.3	22	8	32	8	0.027	<4	42	<3	<2	<5	19	42	10700	45	18200	17200	10500	189	1370	2410	517	19	138	3
36	4	4.8	<10	<10	45	<1	1.3	38	8	33	30	0.133	<4	93	<3	<2	<5	16	55	4080	31	7880	11200	3870	73	4750	866	124	13	113	2
36	5	6.9	<10	<10	56	<1	<.3	21	9	19	8	0.027	<4	52	<3	<2	<5	15	37	7350	40	20200	14000	8830	185	1970	1860	246	21	218	3
37	4	6	<10	<10	62	<1	1	46	14	30	27	0.091	<4	110	<3	<2	<5	16	74	6690	41	19900	14600	5510	191	5500	1150	177	22	146	3
37	5	6.5	<10	<10	50	<1	0.7	35	11	25	14	0.05	<4	76	<3	<2	<5	14	45	6980	38	19600	13100	9100	160	3980	990	604	22	144	3
38	4	4.5	<10	<10	48	<1	1.6	54	7	46	21	0.222	<4	78	<3	<2	<5	27	228	4970	35	7320	13000	3570	61	5550	724	479	22	129	2
38	5	5.6	<10	<10	33	<1	3.3	33	8	23	18	0.075	<4	83	<3	<2	<5	20	168	3590	31	17800	10500	5690	102	4550	1040	57	16	114	2
39	4	6.1	<10	<10	38	<1	0.5	11	7	20	12	0.066	<4	99	<3	<2	<5	5	44	2830	19	18500	7970	4590	124	2330	830	413	36	91	3
39	5	5.7	<10	<10	37	<1	1.4	37	11	26	16	0.087	<4	130	<3	<2	<5	5	47	2260	33	16000	10900	4410	94	2150	944	106	28	74	3
40	4	6.8	<10	<10	44	<1	<.3	33	49	28	34	0.025	<4	190	<3	<2	<5	13	45	5960	82	16100	60800	9100	140	1760	1870	1340	19	169	3
40	5	6.7	<10	<10	35	<1	<.3	27	35	23	36	0.027	<4	138	<3	<2	<5	10	35	4160	58	20500	24500	6580	134	1400	977	596	16	139	2
41	4	6.2	<10	<10	60	<1	1.3	18	9	24	37	0.042	<4	65	<3	<2	<5	13	77	5630	34	20000	10500	10900	218	5210	1410	134	18	97	2
41	5	6.5	<10	<10	25	<1	<.3	16	5	14	19	0.016	<4	39	<3	<2	<5	9	22	3050	17	18200	7560	7180	102	2720	755	59	11	107	2
42	4	4.9	<10	<10	36	<1	1.4	19	8	23	20	0.042	<4	85	<3	<2	<5	13	53	3300	18	7720	8300	4210	152	5630	746	366	12	122	2
42	5	5.2	<10	<10	33	<1	1.1	17	14	24	16	0.046	<4	108	<3	<2	<5	10	40	2590	32	11100	10900	4600	118	4150	797	658	15	93	2
43	4	5.8	<10	<10	27	<1	1.4	34	13	31	17	0.044	<4	123	<3	<2	<5	17	73	3710	34	9150	12100	5790	105	2840	712	236	10	148	1
43	5	6.8	<10	<10	24	<1	<.3	16	6	18	12	0.021	<4	79	<3	<2	<5	8	31	2750	19	18100	8890	5840	129	1360	744	44	12	139	2
44	4	6.4	<10	<10	48	<1	<.3	22	14	67	41	0.048	<4	184	<3	<2	<5	14	76	5790	41	15300	14600	5610	142	2080	1230	246	26	194	3
44	5	6.7	<10	<10	52	<1	<.3	20	14	48	40	0.058	<4	174	<3	<2	<5	15	53	7730	41	18400	13900	8860	146	1970	1700	642	25	192	3
45	4	6.9	<10	<10	21	<1	<.3	17	6	14	12	0.006	<4	51	<3	<2	<5	9	16	3340	19	23200	8670	7580	92	1400	809	39	14	144	2
45	5	7	<10	<10	22	<1	<.3	111	7	15	434	0.012	<4	67	<3	<2	<5	9	18	3660	19	22700	8310	8840	95	2190	931	786	17	120	2

Element concentrations in replicate soil samples collected at 62 sites in Thompson, MB and at the Orr Lake site, 58 km northeast of Thompson.

Sample Site	Rep	pH	Sb	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Ag	Sn	V	Zn	Al	B	Ca	Fe	Mg	Mn	PO4	K	Na	Sr	Ti	Zr
46	4	6.1	<10	<10	17	<1	<.3	14	6	21	8	0.004	<4	35	<3	<2	<5	6	12	2410	17	20300	7770	6440	77	902	678	<5	12	117	2
46	5	6.1	<10	<10	18	<1	<.3	17	7	21	6	0.004	<4	33	<3	<2	<5	9	12	2690	19	18600	8930	6150	84	946	736	66	12	160	2
47	4	7.2	<10	<10	29	<1	<.3	19	14	35	12	0.019	<4	248	<3	<2	<5	10	34	3830	34	17200	11500	7950	102	618	964	211	12	192	2
47	5	7.1	<10	<10	25	<1	<.3	23	13	29	11	0.015	<4	176	<3	<2	<5	10	42	3560	33	20400	11300	7190	101	490	1130	117	12	193	2
48	4	6.2	<10	<10	30	<1	<.3	19	17	42	62	0.033	<4	248	<3	<2	<5	8	38	3140	34	11300	11200	5190	152	2320	846	172	29	106	2
48	5	5.8	<10	<10	30	<1	<.3	15	19	33	15	0.035	<4	255	<3	<2	<5	9	37	2910	34	16300	11100	7950	165	2290	841	203	32	94	2
49	4	6.8	<10	<10	72	<1	0.9	33	33	23	10	0.021	<4	139	<3	<2	<5	21	54	10900	78	16200	66900	10000	229	2070	2930	762	20	101	3
49	5	6.7	<10	<10	67	<1	<.3	49	35	30	59	0.019	<4	123	<3	<2	<5	21	52	10800	74	17200	19700	9950	232	2030	2940	652	20	308	3
50	4	7.2	<10	<10	90	<1	1.2	8	7	16	10	0.029	<4	31	<3	<2	<5	10	39	4480	35	19400	11900	9990	176	1920	1120	116	29	10	3
50	5	6.8	<10	<10	80	<1	1.3	10	6	17	10	0.05	<4	38	<3	<2	<5	9	36	4010	32	16200	10400	6860	162	2190	983	92	25	10	3
51	4	6.6	<10	<10	74	<1	1	18	12	15	10	0.031	<4	43	<3	<2	<5	17	43	8000	49	19400	18500	7650	279	2460	2710	329	28	191	3
51	5	7	<10	<10	74	<1	0.8	22	25	21	10	0.023	<4	68	<3	<2	<5	17	41	8490	61	22400	23900	10100	225	1300	2350	540	30	165	2
52	4	7.5	<10	<10	96	<1	<.3	32	19	58	<5	0.017	<4	78	<3	<2	<5	28	54	16700	76	21500	20500	11500	317	702	4050	480	27	357	2
52	5	7.1	<10	<10	55	<1	<.3	32	36	76	9	0.006	<4	n/a	<3	<2	<5	24	45	10800	76	9940	21200	10700	208	466	4290	332	11	483	3
53	4	6.6	<10	<10	71	<1	0.8	24	14	20	9	0.027	<4	80	<3	<2	<5	22	48	10900	54	20400	21500	9910	250	1510	3220	368	21	172	3
53	5	6.9	<10	<10	82	<1	0.9	25	14	40	7	0.027	<4	68	<3	<2	<5	24	53	13200	66	20600	23600	11400	291	1630	3610	411	27	141	2
54	4	6.9	<10	<10	22	<1	1	18	7	20	15	0.017	<4	68	<3	<2	<5	11	28	3580	30	22100	10400	6400	120	762	1060	117	14	170	2
54	5	5	<10	<10	50	<1	0.9	30	9	27	16	0.077	<4	105	<3	6	<5	18	52	10900	42	7660	16500	8290	132	3680	1950	589	15	285	3
55	4	7.1	<10	<10	73	<1	<.3	26	11	30	<5	0.019	<4	40	<3	5	<5	25	46	13700	55	18700	21000	12500	311	1230	3580	749	27	236	3
55	5	7.3	<10	<10	85	<1	0.5	28	12	36	<5	0.019	<4	45	<3	4	<5	28	51	15000	69	18800	24200	10800	335	1270	4060	274	24	179	3
56	4	6.2	<10	<10	45	<1	0.5	25	29	37	15	0.048	<4	215	<3	<2	<5	8	43	3820	53	17400	20700	5340	116	1490	1360	631	30	136	3
56	5	6.3	<10	<10	47	<1	0.9	39	22	48	51	0.1	<4	220	<3	<2	<5	10	104	4510	50	16200	18500	6960	125	2140	1240	757	22	159	2
57	4	7.1	<10	<10	99	2	<.3	64	87	37	19	0.019	<4	257	<3	<2	<5	24	72	18000	134	13600	91000	11500	269	342	4710	1760	28	334	3
57	5	7.2	<10	<10	99	3	<.3	69	111	42	28	0.019	<4	341	<3	<2	<5	19	90	19600	161	16400	136000	11800	252	609	5530	2230	34	293	2
58	4	6.8	<10	<10	74	<1	0.8	12	9	24	539	0.089	<4	64	<3	<2	<5	9	116	3610	40	18800	11600	5640	154	2160	739	<5	46	60	3
58	5	7.5	<10	<10	100	<1	0.9	13	10	21	19	0.027	<4	64	<3	<2	<5	9	96	3970	42	22200	11300	7280	245	2150	1430	225	50	97	2
59	4	6.3	<10	<10	49	<1	1.1	37	43	31	16	0.039	<4	167	<3	<2	<5	11	34	5060	61	18600	24500	7860	130	3590	1740	1360	32	115	3
59	5	6.4	<10	<10	51	<1	1.1	25	24	21	19	0.043	<4	127	<3	<2	<5	12	39	5100	51	24000	18200	6920	168	4230	1390	528	28	139	3
60	4	5.5	<10	<10	31	<1	1.6	14	6	15	8	0.029	<4	64	<3	<2	<5	11	28	2320	18	18800	6440	4590	137	4030	1090	146	17	82	2
60	5	5.7	<10	<10	34	<1	2.5	16	4	14	5	0.042	<4	69	<3	<2	<5	12	36	2030	15	11200	4720	3790	169	4940	1220	144	12	64	2
61	4	6.2	<10	<10	54	<1	0.5	13	9	18	9	0.033	<4	43	<3	<2	<5	11	41	5160	40	18900	12200	5510	224	3380	2260	292	31	142	3
61	5	6.6	<10	<10	45	<1	<.3	11	10	18	7	0.028	<4	38	<3	<2	<5	8	27	3970	36	18300	10600	5450	184	2600	1580	458	30	114	3
62	4	7.1	<10	<10	23	<1	<.3	20	2	13	17	0.157	<4	56	<3	<2	<5	12	20	3610	5	20000	7480	6180	95	754	860	88	15	169	2
62	5	7.1	<10	<10	66	<1	<.3	28	3	14	26	0.025	<4	60	<3	<2	<5	21	36	9270	10	15300	16100	7390	194	1090	2550	150	21	338	10
Orr Lake Site	1	4	<10	<10	31	<1	<0.3	12	2	5	<30	0.093	<4	12	<3	<2	<5	9	25	4600	27	1690	6090	1620	98	945	975	19	7	199	4
Orr Lake Site	2	4.1	<10	<10	55	<1	<0.3	17	3	11	<30	0.1	<4	36	<3	<2	<5	11	27	8030	39	4340	10900	2470	69	1660	1310	26	19	182	5
Orr Lake Site	3	3.9	<10	<10	75	<1	<0.3	13	2	6	<30	0.093	<4	13	<3	<2	<5	10	22	5510	28	1870	7300	1560	58	1290	1230	24	11	147	4
Orr Lake Site	4	4	<10	<10	35	<1	<0.3	11	2	6	<30	0.094	<4	13	<3	<2	<5	7	18	5140	28	2970	5820	1570	44	1300	872	19	13	149	2